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The Low Power Transceiver (LPT) for Space Applications

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THE LOW POWER TRANSCEIVER (LPT) FOR SPACE APPLICATIONS

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ABSTRACT

Over the last three years, ITT and NASA have collaborated to develop the Low Power Transceiver (LPT). This technology employs a compact, flexible architecture adaptable to a variety of custom communications and navigation configurations for terrestrial, airborne and space applications. The LPT assembly complies with the PC/104 standard and is modular in nature and therefore suitable for implementing a wide variety of integrated functions (e.g., numerous simultaneous software receiver and transmitter channels over multiple frequency bands). The adoption of industry standards coupled with extensive use of programmable circuitry makes LPT extremely reconfigurable. For example, both application-specific and COTS modules (for items like processors and interfaces) may be added to LPT to satisfy mission specific requirements. The inherent flexibility and capability of the LPT are demonstrated by its integration of both communications and navigation functions. At present, LPT supports NASA's Space (TDRSS) and Ground (STDN) Networks for TT&C and science data relay and GPS for navigation, all in a single integrated unit. This capability will be demonstrated on an upcoming Shuttle flight (STS-107) in 2002. This experiment will demonstrate simultaneous communications and autonomous navigation capabilities in an orbital environment, as required for Space-Based Range Safety and Formation Flying applications. LPT development efforts are continuing in order to address new and emerging applications.

INTRODUCTION

The Low Power Transceiver (LPT) is the latest device in a series of software programmable radios sponsored under various technology development initiatives by the National Aeronautics and Space Administration (NASA). Early generations of these software radios were intended to demonstrate the rapid-acquisition capabilities of a matched filter when used in a direct sequence spread spectrum (DSSS) communications systems. Successive iterations of the technology began to realize flexible transmit and receive radios organized around digital signal processors (DSPs). The flexibility of the early systems was demonstrated on numerous occasions by rapidly tailoring the radios to a variety of different NASA communications needs. Examples of this include the application of the Portable Communicator (Portcomm) to the International Space Station's Early Communications System (ECOMM), and the ability of the Software Programmable Advanced Receiver (SPAR) to recover the Inertial Upper Stage (IUS) booster's telemetry link via the Tracking and Data Relay Satellite System (TDRSS). In both cases, an immediate NASA need was solved quickly and cost effectively.

Technological advancements in digital signal processing and RF components, together with an ever present need for smaller and lower powered spacecraft subsystems, formed the basis for original LPT designs. The original LPT concept centered on a novel application of a digital matched filter to integrate the functions of spacecraft communications and navigation in a small, ultra low power implementation. However, as the program evolves, additional spacecraft system infrastructure is being integrated and advanced signal processing is being added. As a result, a new class of device is emerging that truly enables next generation space missions and operations concepts. As will be illustrated, this new device is a highly scalable and programmable platform suitable for mission-specific tailoring, on-orbit reconfiguration, and autonomous operation.

THE LOW POWER TRANSCEIVER

Architecture

The LPT is a collection of interchangeable hardware modules that form a software programmable platform for a variety of general purpose or specialized communications, navigation and control capabilities. The hardware modules are based on the mechanical and electrical specifications found the PC/104 Consortium's PC/104-*Plus* Specification.[1] Modules that comprise the basic transceiver include:

- I/O Module
- Power Supply Module
- Digital Signal Processing Module
- RF Transmitter Module
- RF Receiver Module
- Power Amplifier Module

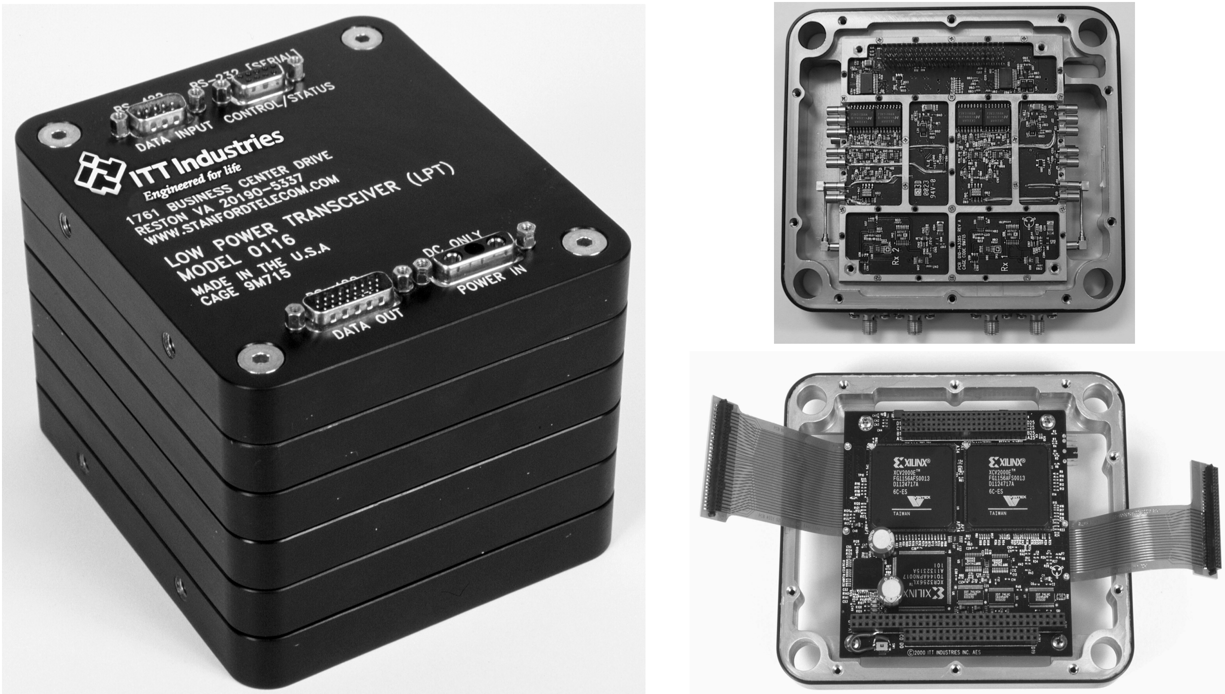

Figure 1. The Low Power Transceiver and Hardware Modules
(clockwise from left, the "Core" LPT, the Dual Receiver Module, and the 2nd Generation DSP Module)

These six modules stack together to form a complete LPT assembly in its most common form. Figure 1 shows the assembled (approx. 5"x5"x5") LPT module stack and top views of two hardware modules. Each module consists of one or more printed circuit boards (PCBs), a housing ring to which the PCBs mount, a heat plate and thermal pads (not shown in the figure), and EMI gaskets (also not shown). Once assembled, the modules stack together and are rigidly fastened using four connecting rods, as illustrated in Figure 2. Both PC/104 standard and non-standard stackable connectors provide for electrical connectivity between various modules. Additionally, two "chimneys" run vertically inside the housings and provide for additional module-to-module cabling. When assembled, the housings form a rigid structure designed for the most rugged environments found in existing launch vehicles. Furthermore, the combination of heat plates, thermal pads and rigid structure provide a low resistance thermal path between hot components and a cold plate to which the LPT is mounted. Finally, the heat plates and EMI gaskets provide sufficient RF isolation between modules to simultaneously operate in both transmit and receive directions and to satisfy EMI/EMC requirements.

Functionally, the core LPT implementation contains a dual band RF receiver and a single band RF transmitter. In typical implementations, the band assignments support a two-way S-Band communications system via NASA's TDRSS or Spaceflight Tracking and Data Network (STDN) and an L1 GPS receiver, as shown in Figure 3.

The Dual Receiver Module performs the functions of low-noise amplification (LNA), band limiting, frequency conversion, automatic gain control and digitization. Each receiver path functions independently, and is designed generically such that it may be tailored to operate over a wide range of frequencies. Each receiver is made up of three PCBs: an LNA board, a synthesizer board and a receiver board. In current implementations, the radio may be tuned to operate at any RF from about 300 MHz to 2500 MHz simply by populating these PCBs with appropriate discrete components (filters, VCOs, matching networks, etc.). The most recent versions of this hardware will support instantaneous bandwidths up to 50 MHz, limited by the 100 Msps, 8-bit A/D converters. The digitized samples from each receiver feed a time-multiplexed bus structure implemented over a stackable connector. The bus structure allows as many as eight Dual Receiver Modules to be stacked into a single LPT. Each module is addressed sequentially, and samples are received by a DSP Module.

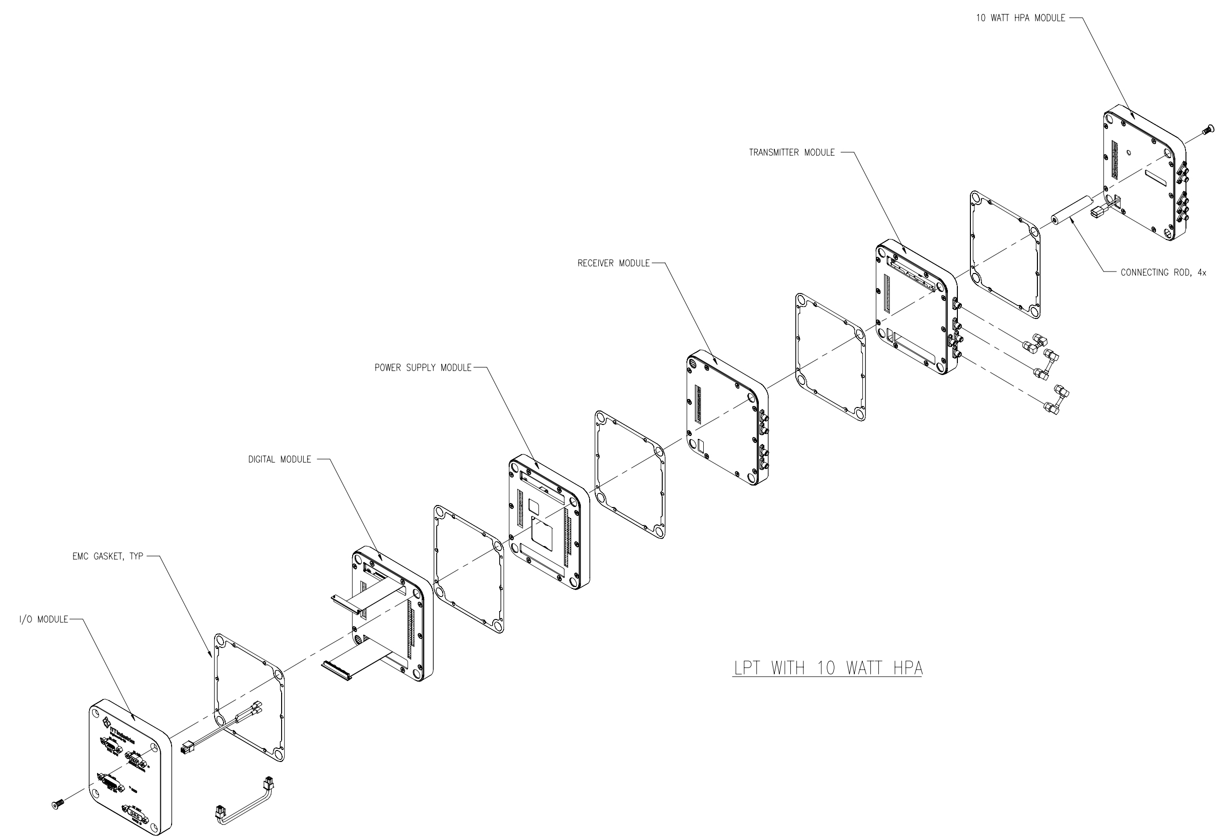

Figure 2. Exploded View of the LPT

The Transmitter Module performs the functions of D/A conversion, frequency conversion, band limiting, automatic level control and amplification up to 1 watt of RF power. Like the receivers, the Transmitter Module contains three PCBs: a transmitter board, an amplifier board and a synthesizer. It is designed to be tuned over a range of frequencies between 1800 MHz and 2500 MHz by populating the PCBs with the appropriate discrete components. The smaller tuning range is limited only by the power amplifier board – the remaining circuitry is suitable for use down to approximately 300 MHz. The most recent version

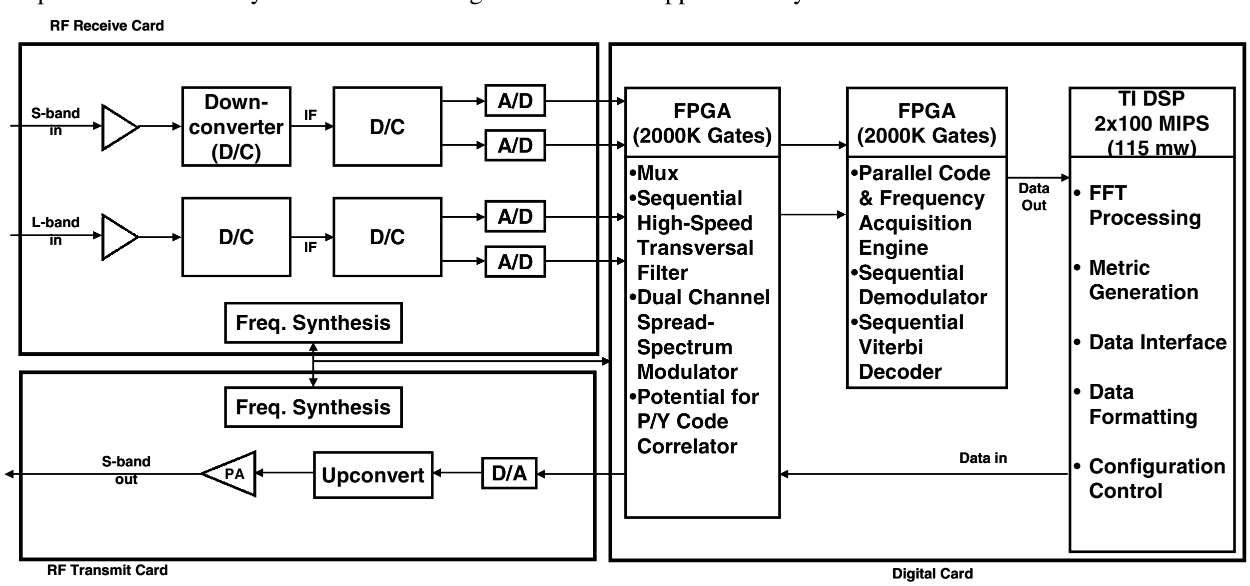

Figure 3. Block Diagram of the LPT

of the Transmitter Module supports instantaneous bandwidths up to 70 MHz, and is limited by the 70 MHz IF and the 14-bit, 160 Msps D/A converter. Two operationally independent Transmitter Modules may be stacked in a single LPT.

Frequency synthesis in the LPT is concentrated in the Transmitter Module. An external input or an internal 10 MHz temperature compensated crystal oscillator (TCXO) provides the reference for the two oscillators required by the transmitter. Multiple copies of the 10 MHz reference and a second reference (fundamental frequency for TDRSS synthesizers) are distributed from the Transmitter Module for use in the receiver synthesizers. The receiver synthesizers use the distributed references for the two oscillators required by each receiver chain.

The DSP Module is the foundation of the software radio, and performs all modulation and demodulation functions in the LPT as well as some data post processing functions. Each DSP Module contains one or more Xilinx Virtex, Virtex-E, or Virtex-II series FPGAs, a Texas Instruments DSP chip, memory for program storage, clock synthesis and distribution circuitry, a UART and various data transceivers. In general, the FPGAs contain the high-speed modulation and demodulation logic while the DSP is responsible for low-rate signal processing, metric generation and overall control and monitoring of the LPT. The module contains sufficient Flash memory to store two complete images of both the FPGA and DSP firmware. This feature enables the LPT to be remotely reprogrammed in its entirety and provides a failsafe in the event that an unaccounted for error occurs during the reprogramming. Selection of the “boot bank” is controlled external to the LPT.

Software Programmable Signal Processing

Due to its flexible, programmable nature, the LPT is suitable to host virtually any form of modulation or demodulation. In existing implementations, the LPT firmware is designed to accommodate up to 16 receive RF bands, and to process up to 16 independent data channels from any one or all of the RF bands. In a typical configuration, twelve of these data channels are dedicated to processing GPS signals, leaving four channels for data communications. Each of these channels is physically identical, operates independently, and may be fed from any RF input band.

Like its predecessors, the heart of the LPT demodulator is a digital matched filter. The patent-pending, 256-stage structure is innovative in its ability to simultaneously perform the parallel correlations required for the rapid acquisition of DSSS signals as well as perform the more straightforward correlations required to track the code phase of numerous other DSSS signals. This feature is accomplished by breaking the correlator into smaller pieces and re-allocating the acquisition hardware for the purpose of tracking. Doing so eliminates the need for a dedicated structure that is used only during the initial time period of a communications session, and is extremely valuable when required to implement hardware efficient structures due to the limited resources of an FPGA.

In addition to the parallel correlator/matched filter, the FPGA PN code acquisition engine includes dedicated logic to coherently and non-coherently extend the integration interval for each code offset in order to minimize acquisition time. In order to maximize the coherent integration time, eight parallel frequency converters and correlators are used to span large frequency intervals when the carrier frequency uncertainty of a signal exceeds the symbol rate. In conjunction with this hardware, a false-lock algorithm is implemented to protect against cross-correlated codes and false correlation peaks. In a typical scenario, the LPT’s acquisition engine is capable of searching thousands of PN code offsets in each of its eight parallel correlators in only 100 milliseconds.

The demodulator typically implemented in the LPT is capable of processing both phase shift keyed (PSK) and more general linear phase modulated (PM) signals, either spread or non-spread, as required by NASA’s TDRSS and STDN communications systems and by GPS. Coherent tracking of symbols, carrier and, when necessary, PN code is accomplished for data rates from 50 bps to 1 Mbps. The demodulator also includes Viterbi decoders and differential decoders for its communications channels. Channel metrics generated by the demodulator include frequency offset, signal level, Eb/No, lock detectors, and acquisition time.

The modulator is a dual-channel structure capable of modulating two independent data streams at data rates up to 4 Mbps each using BPSK, QPSK, OQPSK, and linear PM. Like the demodulator, the modulated signal may either be spread or non-spread. In addition to the standard modulation types listed, a form of baseband filtered OQPSK is implemented in the modulator. This modulation affords a near-constant envelope waveform that may be configured to trade between channel bandwidth efficiency and RF power amplifier efficiency, yet is suitable for use with receivers that implement integrate-and-dump type matched filters. Further, the input data streams may independently be differentially encoded, convolutionally encoded, convolutionally interleaved and Manchester encoded, as desired.

In addition to the generic communications receiver, specific signal processing is incorporated in the LPT to process GPS signals using the civilian C/A codes. The existing LPT implementation performs both code and carrier phase measurements, and maintains an estimate of time. LPT also recovers and decodes each tracked spacecraft's ephemeris and almanac broadcasts. These phase measurements and broadcast messages may be combined with various forms of application-specific solution processors to form estimates for position, velocity and time as required by a particular mission. The most notable LPT GPS capability is its "time to first fix." On average, when provided with no a priori information regarding the GPS constellation relative to LPT position, and whether on the Earth's surface or in low Earth orbit (LEO), the LPT is able to search for all spacecraft, over the entire Doppler uncertainty region, and over all PN code offsets, in order to produce an estimate of position in approximately three minutes. This average time accounts for the randomness in acquiring the first four signals, for obtaining frame synchronization and for receiving the full ephemeris download from each of those four spacecraft.

CANDOS on STS-107

The first demonstration of the LPT in an orbital environment will occur during the STS-107 mission of the Space Shuttle. Termed the "Communications and Navigation Demonstration on Shuttle" (CANDOS), the demonstration will serve primarily to prove the functionality and capability of the LPT while in orbit. As a secondary goal, the demonstration will prove the LPTs ability to qualify for and survive the flight environment of the Shuttle cargo bay. Because this mission is expected to be relatively benign, no attempt has been made to make the LPT tolerant to radiation (refer to the "Evolution" section for details regarding space adaptation of the LPT).

This technology demonstration will be conducted as part of an integrated Hitchhiker (HH) cross-bay payload deemed the Fast Reaction Experiments Enabling Science, Technology, Applications and Research (FREESTAR). Experiment components include one LPT electronics stack, three S-band antennas and one L-band antenna, all mounted to the top of the HH

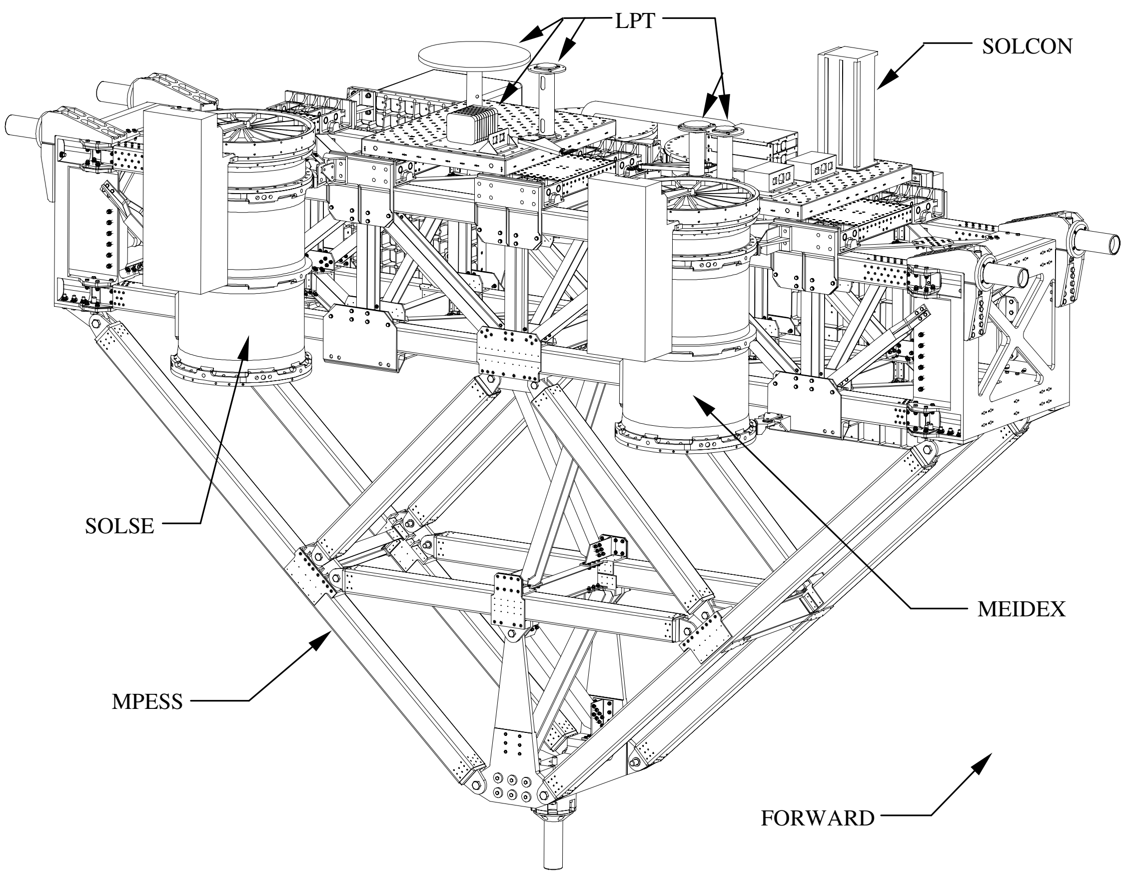

Figure 4. STS-107 Hitchhiker Cross-Bay Bridge with LPT and Other Experiments

Multi-Purpose Equipment Support Structure (MPESS) via two HH Single Bay Pallets (SBP). The general arrangement of the FREESTAR payload is shown in Figure 4.

The LPT will utilize four antennas during CANDOS operations. The transmission beams and antennas are fixed in orientation and are not pointable, requiring Shuttle pointing maneuvers to facilitate communication with TDRSS and/or STDN ground stations. An 18" S-band antenna with a narrow ± 10° beam width provides the required gain to transmit high-rate data (i.e., up to 300 kbps) to TDRSS. Two 3” S-band antennas have wider ± 35° beam widths. One 3” antenna is used to transmit data to the STDN ground stations, while the other 3” antenna is used to receive both TDRSS and STDN transmissions. The third 3” antenna provides for GPS signal reception and also has a ± 35° beam width. The LPT TDRSS (and STDN) forward link (uplink) frequency is 2106.40625 MHz and the TDRSS (and GN) return link (downlink) frequency is 2287.5 MHz (utilizing Left-Handed Circular Polarization to work with the TDRSS MA system). Two Shuttle crew compartment Standard Switch Panel (SSP) switches will be incorporated to prohibit inadvertent RF transmissions from the antenna. An additional inhibit will be provided through the HH avionics power relay to the LPT.

LPT will be activated and deactivated by ground commands via the HH avionics. All other experiment commanding and telemetry will be primarily performed via direct communications between LPT and the STDN and/or TDRSS; backup command and telemetry capability will be provided via the HH avionics (use of direct to ground communications is required to achieve full experiment success). The astronaut flight crew will also be able to enable and disable the payload via the SSP.

The CANDOS experiment requires the on-orbit demonstration of six payload objectives: GPS Navigation, STDN Communications, TDRSS Communications, On-Orbit Reconfiguration, Space Based Range Safety, and Mobile IP.

The GPS Navigation experiment will characterize the performance of LPT’s GPS receiver. In conjunction with this experiment, an extended Kalman filter – developed by NASA’s Goddard Space Flight Center (GSFC) and referred to as the GPS Enhanced Orbit Determination Experiment (GEODE) software – will be used to estimate position and velocity (i.e., the state vector) of the Shuttle. CANDOS will be the first application of GEODE on orbit, and will demonstrate the capability of a spacecraft to determine its own state precisely enough that it could navigate itself autonomously.

The STDN and TDRSS Communications experiments will demonstrate and characterize the basic communications capabilities of the LPT. During the Space Based Range Safety demonstration, the LPT will simultaneously communicate with both TDRSS and STDN ground stations while producing position and velocity estimates based on its GPS receiver. This experiment will demonstrate for the first time on-orbit the ability of a single device to provide the functions of both position location and command destruct. The use of a Space Based Range will aide in the reduction of launch costs and will allow launches from virtually any location on Earth without increasing the risk of public safety.

The software programmability of the LPT will be demonstrated during an on-orbit reconfiguration of the DSP firmware. During this experiment, a slightly modified image of DSP firmware will be uploaded to the LPT’s alternate Flash RAM bank via TDRSS. When the upload is complete, a command will be sent to switch the boot bank in the LPT and re-boot the experiment.

All communications conducted between the operations control center and the LPT throughout the experiment will use the Internet Protocol (IP). Both TCP/IP and UDP/IP varieties will be used in order to demonstrate the feasibility of using the protocol to communicate with future spacecraft. All control and monitoring software embedded in the LPT experiment relies on the IP protocol, which is implemented using a commercial off-the-shelf (COTS) version of Linux running on a Pentium-class processor. In fact, this configuration will allow ground controllers to use standard internet tools to manage the experiment, including Telnet and FTP. In addition, a recent extension to the IP protocol stack known as Mobile IP will be demonstrated. Mobile IP will autonomously address IP packets as required to route message traffic between the LPT and the control center, regardless of the ground station (TDRSS or STDN) it is communicating through. This is important since the Shuttle will be flying in and out of view of numerous ground stations. As this occurs, the network topology will change, requiring messages to be diverted along different paths. The ability of the protocol to make this transparent to the end user is crucial for the viability of its use in future missions.

EVOLUTION

In an effort to maintain LPT as a cutting edge signal processing platform, its development has evolved through a series of generations since the program inception in the fall of 1998. Each new generation has taken advantage of the latest commercial components in order to reduce the volume, mass and power consumption of the LPT while simultaneously delivering increased signal processing capability. This improving signal processing capability has allowed for an expansion of LPT functionality in the form of increased channel density, higher bandwidths, and the integration of additional communications and navigation infrastructure. Emerging mission requirements and operations concepts form the basis for which new features are added. In this manner, each new generation of LPT hardware and firmware becomes an enabler for a new class of mission.

Generation Overview

The first generation LPT was the first device to integrate the functions of communications and navigation using a single signal processing engine. It offered twelve receiver channels, two receive RF bands (TDRSS/STDN & GPS), two transmitter channels, and a single transmit RF band (TDRSS/STDN) with one watt of RF output power. This arrangement not only conserves volume, mass and power for any spacecraft that requires these functions, but is an enabler for microsatellites and for Space Based Range Safety. This first generation device consumed less than 8 watts of DC power for receive-only functions, and about 12 watts when the transmitter was also enabled.

The second generation LPT built on the success of the first generation by adding four additional receiver channels (brining to total to 16), expanding the number of transmit and receive RF bands, and by adding several new functions. The emerging mission need targeted during the second generation development is termed Formation Flying. In this operations concept, numerous spacecraft fly in "formation" in order to improve science and reduce the risk associated with a single, larger and more expensive spacecraft. In order to realize this concept, each spacecraft assumes new requirements for both communications and navigation. Specifically, communications crosslinks between spacecraft allow the formation to operate in a coordinated manner, and relative position information is crucial in order to prevent spacecraft from colliding. In order to address these new needs, the second generation LPT also added: a crosslink capability, a phased array beamforming capability, a RAKE receiver capability, and a multi-user detection (MUD) capability.

The crosslink addition consists of a waveform suitable for various formation network types (star network, mesh network), and is suitable for use in either frequency division duplexed (FDD) or time division duplexed (TDD) systems. The crosslink facilitates high data rate communications between formation cluster members as well as inter-spacecraft ranging.

The trio of beamforming, RAKE and MUD were added to mitigate various forms of interference that may be introduced when flying in formation clusters. Beamforming was a logical addition for two reasons: it permits multiple, simultaneous, high-gain RF links as required when communicating with numerous cluster members; and it provides spatial filtering to mitigate co-channel interference from other cluster members. The integration of the beamformer with the receiver dramatically simplifies operation of the array as compared with traditional, separate implementations. The RAKE receiver will be used to guard against multipath produced when signals reflect off of other cluster members. Multi-user detection will help mitigate the effects of co-channel interference. All three of these signal processing augmentations (software only!) mate well in the LPT architecture. Each requires multiple signal paths, or channels, something LPT readily offers. Each also requires similar or identical signal processing as a typical receiver, resulting in extremely efficient implementations of these three techniques.

In addition to the augmentations listed, the second generation LPT also added the ability to use the new GPS civilian code on the L2 carrier. This new code, known as the replacement code (R/C), will permit civilian GPS receivers to estimate atmospheric effects in order to produce a more accurate position solution. The LPT will be ready to support these new signals when they are broadcast by the next fleet of GPS spacecraft.

The third generation LPT, currently under development, will further improve channel density, increase channel bandwidth, and increase RF receiver and transmitter band density. Additionally, the third generation will be the first LPT generation built to survive the effects of long-term exposure to the natural radiation environment found in space. This topic will be addressed further in the next sub-section. Specific signal processing modifications have yet to be identified, but candidates include integrating the GPS solution software (GEODE), adding GPS-based attitude determination, and augmenting the MUD algorithms added to the second generation LPT.

Mitigating Radiation Effects

The intended operational environment of the LPT has always included the space environment. Though the first two generations of the LPT were focused more on proving functionality and performance and less on environmental aspects, the third generation will address the issues of high reliability and radiation tolerance. Three distinct focus areas present themselves in the LPT with respect to addressing these issues: power supplies, RF hardware, digital hardware. The power supply issue is most easily addressed by incorporating existing high reliability and space qualified components. Though the technologies used in the LPT use voltages not yet common in most space hardware, vendors are anticipating the migration and are producing qualified hardware. Because of the materials commonly used in RF hardware, the components used on the RF boards are typically qualifiable without significant risk. Of much greater susceptibility are the digital components, specifically the FPGAs, DSP and A/D and D/As used in the LPT. The DSP problem is solved either by using existing, radiation tolerant DSP chips or by embedding the DSP function into the FPGAs. This latter technique is only recently possible due to the very high density FPGA devices now available. The A/D and D/A problem is primarily one of single event latch-up (SEL), and care must be taken in selecting and testing these components prior to use.

The single largest "enabler" technology for the LPT is its heavy reliance on FPGAs. Fortunately, alternatives now exist for utilizing very high density FPGA components in radiation environments. The third generation LPT will use a combination of FPGAs from both Actel and Xilinx. Actel FPGAs use anti-fuse technology, are inherently SEL tolerant, and are either single event upset (SEU) tolerant or use built-in redundancy to avoid this concern. The Actel FPGAs are used for all functions that must be available upon application of power to LPT or that are required to support the higher density Xilinx FPGAs. The third generation LPT features Virtex-II FPGAs with "equivalent" ASIC gate densities as high as eight million gates. This family of FPGAs has not been characterized in a radiation environment at the time of publication of this paper, but it is expected that the Virtex-II will behave similarly to the Virtex and Virtex-E families, both of which have been characterized.

Xilinx uses an epitaxial layer in its CMOS FPGAs in order to obtain immunity to SEL as well as yield total ionization dose (TID) levels in excess of 300 krads (Virtex-E devices), ensuring that device survivability in space is not an issue. The issue then is one of SEUs and single event functional interrupts (SEFIs). The SEFIs may be grouped into two types: power on reset (POR) and JTAG. Each of these SEFIs will result in a complete interrupt of device functionality and require external logic to recover operation. Fortunately, the cross section of circuitry susceptible to these interrupts is so small that the probability of seeing either of them is exceedingly small (though it is quantifiable). The eventuality that one or both of these interrupts will occur in an LPT as it is currently designed is a certainty.

In order to combat SEUs in the Xilinx parts, a number of techniques are available and have been thoroughly characterized by Xilinx in radiation test facilities. In essence, by following the manufacturers recommendations, including partial reconfiguration and triple module redundancy (TMR), it is possible to reduce the effects of SEUs on device functionality to zero. A considerable research effort is underway to implement and verify this aspect using the third generation LPT.

THE FUTURE

The generational evolution of LPT is far from over. We have already described the vision for a so-called fourth generation LPT, though we've coined a new term: the Miniature Transceiver (MinT – how innovative!). This new generation will evolve the LPT packaging system into a miniature form factor while preserving or improving upon the core LPT capabilities. In its own right, the third generation LPT platform is a compact device measuring approximately 100 cubic inches in volume. However, the MinT will strive to be only 8 cubic inches in volume – a cube measuring approximately two inches on a side. This will be accomplished by following the same formula used in the earlier generations of LPT: take advantage of latest-generation, commercially available technology while keeping an eye on the environmental requirements of space applications. This new, light-weight form factor will help revolutionize spacecraft design by allowing the transceiver to be placed near or inside antenna structures, virtually eliminating cable losses that plague existing spacecraft and limit the bandwidth available for science data. Additionally, it will act as an enabler for a new generation of nano-satellites whose entire mass is less than a conventional transceiver/transponder.

New packaging schemes will be developed that expand upon the modular foundation of the first three generations of LPT, improving bottlenecks and trouble spots inherent to the existing design. Printed circuit boards will most likely be assembled using chip-on-board techniques in order to eliminate the size restriction imposed by chip packages. Likewise, innovative and ultra-high-density signal routing will be utilized in order to provide a dramatically improved bandwidth potential, allowing the new form factor to take advantage of future advancements in signal processing speed and density.

CONCLUSION

The Low Power Transceiver is a flexible, software programmable radio that will revolutionize the state-of-the-art in spacecraft TT&C and navigation technology. The foundation of the concept has been thoroughly developed and demonstrated, and its promise has been exploited by cost-effectively adding new capabilities and signal processing. The latest generation of the hardware will be suitable for the harsh environment of space, where it will enable entirely new operations concepts and missions.

The STS-107 mission will demonstrate the LPT's TDRSS, STDN and GPS capabilities, and will pave the way for future missions that rely on the use of autonomous spacecraft navigation, IP in space, and Space Based Range Safety. As it continues to evolve, the LPT will continue to enable newer, smaller, lighter, and more complex spacecraft. Specifically, the MinT promises to be a breakthrough technology for emerging nanosat missions currently being planned.

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13. ABSTRACT ***(Maximum 200 words)***

Over the last three years, ITT and NASA have collaborated to develop the Low Power Transceiver (LPT). This technology employs a compact, flexible architecture adaptable to a variety of custom communications and navigation configurations for terrestrial, airborne and space applications. The LPT assembly complies with the PC/104 standard and is modular in nature and therefore suitable for implementing a wide variety of integrated functions (e.g., numerous simultaneous software receiver and transmitter channels over multiple frequency bands). The adoption of industry standards coupled with extensive use of programmable circuitry makes LPT extremely reconfigurable. For example, both application-specific and COTS modules (for items like processors and interfaces) may be added to LPT to satisfy mission specific requirements. The inherent flexibility and capability of the LPT are demonstrated by its integration of both communications and navigation functions. At present, LPT supports NASA's Space (TDRSS) and Ground (STDN) Networks for TT&C and science data relay and GPS for navigation, all in a single integrated unit. This capability will be demonstrated on an upcoming Shuttle flight (STS-107) in 2002. This experiment will demonstrate simultaneous communications and autonomous navigation capabilities in an orbital environment, as required for Space-Based Range Safety and Formation Flying applications. LPT development efforts are continuing in order to address new and emerging applications.

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